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Soil Conservation Service
Engineering Division

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GEOLOGIC INVESTIGATIONS FOR WATERSHED PLANNING

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I. INTRODUCTION

Purpose and Scope

This technical release outlines general procedures and methods for conducting geologic investigations related to sedimentation, engineering geology, and ground water for work plan development. It replaces tentative technical release number 17 issued in March 1961. For information on detailed procedures and criteria not included in this technical release, the field geologists are referred to the Engineering and Watershed Planning Units for advice and assistance and to existing Engineering and Watershed Planning Unit and Washington Office memoranda, technical releases, guides, and handbooks.

Scope and Intensity of Geologic Investigations for Work Plan Development

Three general classes of intensity of investigations in watershed planning are recognized--field examination, preliminary investigation, and work plan development. Guide lines for determining the intensity of investigation for each phase of geologic work normally encountered in work plan development are included under appropriate subject headings in this technical release.

In accordance with national policy, only those surveys and investigations are to be undertaken that are needed to develop an adequate watershed work plan. A primary consideration, from a technical standpoint, is that a firm cost estimate be developed. Determination of the scope and intensity of investigations for general work plan development is the responsibility of the state conservationist. The geologist must determine, within the framework of state and national policy, the intensity of investigation needed for geologic purposes for each phase of work. This determination is made at the time the work outline is developed. Items which need to be considered in determining intensity include extent of damages involved, benefits to be derived from a proposed watershed protection program, cost of installations, benefit-cost ratios, hazards from failure involved, sizes of structures, purposes of structures, complexity of geologic conditions, and the requirements of state agencies for approval of design for structures.

The geologist will collect the geologic data needed by the economist and engineer for arriving at firm costs and benefits. The economist will need physical data to evaluate monetary damages to cultural improvements, water supplies, navigation and other enterprises, and the reduction of damages to be anticipated as a result of installation of the program. The engineer needs data concerning: erodibility of materials and sediment yields, as they affect the design of proposed engineering features; geologic characteristics of the site; the availability of suitable material for borrow, aggregate for concrete, riprap, and filter; the probable depth to firm materials; the

probable rock excavation required; probable drainage and foundation problems; ground water conditions; and the cost estimate of detailed investigation.

General Sources of Information

In order for the geologist to acquaint himself with the problems involved and to plan and schedule the work to be done, readily available data pertinent to the watershed should be assembled and reviewed prior to initiation of extensive field studies. Sources of such information are: (1) geological maps and reports, (2) soil survey reports and maps, (3) water supply and water use reports, and (4) other maps and reports.

Geologic studies in a watershed generally require numerous contacts with other agencies - federal, state, and local. The following is a partial list of possible sources of information, exclusive of agencies of the U. S. Department of Agriculture, which might provide helpful information during the course of a survey:

Federal	State	County and Local
U. S. Geological Survey	Conservation Comm.	Road & Street Depts.
Bu. of Reclamation	Health Departments	Water & Sewage Depts.
Bu. of Public Roads	Highway Departments	Libraries
Corps of Engineers	Geological Surveys	Power Companies
Bureau of Mines	Water Resource Agencies	Railroad Companies
Bu. of Land Management	Universities & Colleges	Large Industries
Fish & Wildlife Service	Planning Board & Comm.	Long-time Residents
Public Health Service		

Preliminary Investigation for Work Outline Development

A preliminary investigation is to be completed prior to development of a work outline and plans for field studies for work plan development. The preliminary investigation will afford the geologist an opportunity of acquainting himself with the watershed. He should consider the following items during this investigation.

(1) The geology, physiography and land use of the watershed as they relate to erosion, transportation and deposition of sediment.

(2) The nature and probable extent of sedimentation and related damages influenced by watershed conditions.

(3) Probable sources of damaging sediment.

(4) The location of existing reservoirs and ponds.

(5) The general geology of possible dam sites.

(6) Geologic conditions influencing channel stability and improvement.

(7) Geologic conditions which may influence ground water movement and recharge.

(8) Ground water conditions.

Geologic aspects, hydrologic conditions and other considerations are needed to evaluate the project and to recommend planning priorities, as outlined in Section 3 of the Watershed Protection Handbook [1].1/

1/ Bracketed numbers indicate appended references.

II. SEDIMENTATION

Nature and Occurrence of Sediment and Erosion Damages

Sedimentation implies the processes of erosion, entrainment, transportation, and deposition of sediment. Sediment is defined as solid material that is being transported or has been moved from its site of origin by air, water, gravity or ice. Erosion is defined as the detachment and movement of rock or mineral materials by wind, moving water, ice, gravity or other agents.

For purposes of evaluation, sediment and erosion damages are separated into two categories: (1) direct damages and (2) indirect damages. Direct damages result in primary (first hand) impairment of properties, facilities and utilities of man. Indirect damages are secondary (associated) damages related to or resulting from primary or direct damages. Computations of monetary damages are the responsibility of the economist. The geologist is expected to supply data on physical damages which the economist needs for his calculations. In some instances, such as in cleanup costs, sediment damages can be estimated only in monetary terms, in which case the geologist and economist should jointly decide who should estimate such damages. Thorough knowledge of the use of information by the economist and close coordination with the economist is necessary to avoid collection of unnecessary data.

Sediment Damage

Damage to properties, facilities and utilities as a result of sediment in transit or sediment deposition is considered as sediment damage. The following items illustrate different types of sediment damage:

Infertile deposition.--Relatively infertile modern sediment may be deposited on flood plains or on colluvial soils. Modern sediment is that resulting from culturally accelerated erosion. It may take various forms, such as over-bank splays, fans, or vertical accretion deposits. Infertile sand or gravel deposits commonly cause this type of damage, but silts and clays derived from subsoil erosion, if low in nutrient elements, are also harmful in some areas. General principles of stream and valley sedimentation; criteria for recognition of modern valley deposits; and the relationship of stream and valley sedimentation to flood-control problems have been outlined by Happ, Rittenhouse, and Dobson [2].

The degree of damage by deposition of infertile materials depends on the type of material, the depth of deposit, and the rate of deposition as well as the productivity of the land in its original state. As an example, consider two areas of silt loam flood-plain soil which have been damaged by sand. One has been damaged by a deposit of 16 inches of sand added gradually, at the rate of one inch a year for 16 years. It has been possible to mix the sand with the surface eight inches (plow depth) of soil each year. Therefore, although the productive capacity of the soil has diminished to 50 percent of the original

capacity, it is still in production. In contrast, the other area has received a deposit of only eight inches of sand, all of which was deposited in one year. Under normal practices there would not be much mixing of this sand with the old soil below. Unless special treatment is used, it might be taken out of production and for all practical purposes lost to cultivation.

Swamping.--Swamping is any impairment of lateral or vertical drainage of flood-plain soils due to sediment deposits. Swamping may be caused by filling of stream channels with sediment which raises the water table; or by the formation of natural levees by modern sediment deposits which prevents proper surface drainage; or by deposition of fine-grained sediment upon flood plain soils resulting in puddling or reduction of permeability and prevention of internal drainage. Although swamping is a direct result of deposition, it is evaluated as a separate damage. Swamping often affects extensive areas of flood plains, and in its most serious form will make formerly good cropland unfit for agricultural use.

Reservoir sedimentation.--Deposition of sediment in reservoirs results in the loss of storage capacity needed for water supply, power, recreational, irrigation, flood control, and other purposes. As a result the services dependent upon the capacity are impaired. Damage to natural lakes is included in this category as well as artificial reservoirs.

Water treatment.--Cities and industries which derive their water from surface sources, whether stream or reservoir, incur costs for the removal of fine suspended mineral matter in the raw water. A part of the expense of treatment may be considered a damage since it is partly preventable.

Damage to hydro-electric power facilities.--After a power reservoir is completely filled with sediment, the power plant no longer has reserve, or carry-over, storage but must depend upon run-of-the-river flow entirely. Although this may greatly reduce the amount of power that can be generated, most power plants continue to operate under these circumstances on a reduced power output basis. At this stage a new sediment damage may occur. Coarse materials may move out of the silted-up reservoir, through the intake and into the turbines. This causes excessive wear on the turbines, runners and other equipment and necessitates more frequent overhaul and replacement.

Damage to transportation facilities.--Sediment deposits damage highways and railways by collecting in ditches and culverts and upon the roadways and by filling and constricting channels beneath bridges.

Drainage ditch and irrigation canal sedimentation.--Drainage ditches, irrigation canals, and floodways are usually vulnerable to sedimentation because of the low grades developed. As they become filled with sediment, and often with vegetative growth, they lose their capacity to transport water. This results in more frequent overflow of flood-

ways and drainage ditches. It may raise the water table adjacent to drainage ditches and/or impair effectiveness of lateral outlets. Silting of irrigation canals reduces the amount of water which may be delivered to irrigated areas at critical times resulting in loss of crop production.

Damage to navigation channels.--When navigation channels, pools, and harbors become shoaled because of sediment deposits, movement of vessels may be limited to high water periods or halted entirely.

Increased flood stages.--When stream channels become clogged with sediment and flood plains are raised by sediment deposits, flood crests for the same discharges are constantly forced to higher elevations and floodwater damage increases. The damage may be caused by several conditions. If the flood plain is bounded by low terraces and the channel and flood plain are aggrading at approximately the same rate, increasing flood damage will take place on the terraces, but not on the flood plain, except in the case of buildings or other fixed installations. If the channel is aggrading at a faster rate than the flood plain, then there will be increasing floodwater damage on both flood plain and terraces. If the channel is enlarging at a rate equal to the rate of flood plain aggradation, no increase in floodwater damage will take place on either flood plain or terraces. Figure 2-1 illustrates these various conditions.

Damage to urban and rural fixed improvements.--After most floods, deposits of sediment are found on streets and in homes, factories, sewers, wells, and other places where they cause damage due to cost of removing this sediment or cleaning and replacement of equipment and materials.

Recreational losses.--Sediment may cause the impairment of recreational values, such as damage to fish, wildlife, and recreational facilities (beaches, bathing facilities, etc.)

Erosion Damage

Erosion is the detachment and movement of individual particles or masses of materials by various forces such as wind, water, ice, gravity, etc. Water erosion is of most concern in watershed planning work. Water erosion may be classified into two broad types--sheet erosion and channel erosion. This system is convenient as a basis for determining the kinds of measures needed for control and requirements for monetary evaluation. Thus, sheet erosion generally can be controlled by land treatment measures, whereas structural measures are generally required for the control of channel erosion. Since structural works of improvement must be justified, on a monetary basis, evaluation of damages due to channel erosion is usually necessary. Various types of water erosion are listed in the following paragraphs, together with associated types of damages. In addition to the types of damages outlined, channel erosion also provides sediment to stream systems which may create additional downstream sediment damages.

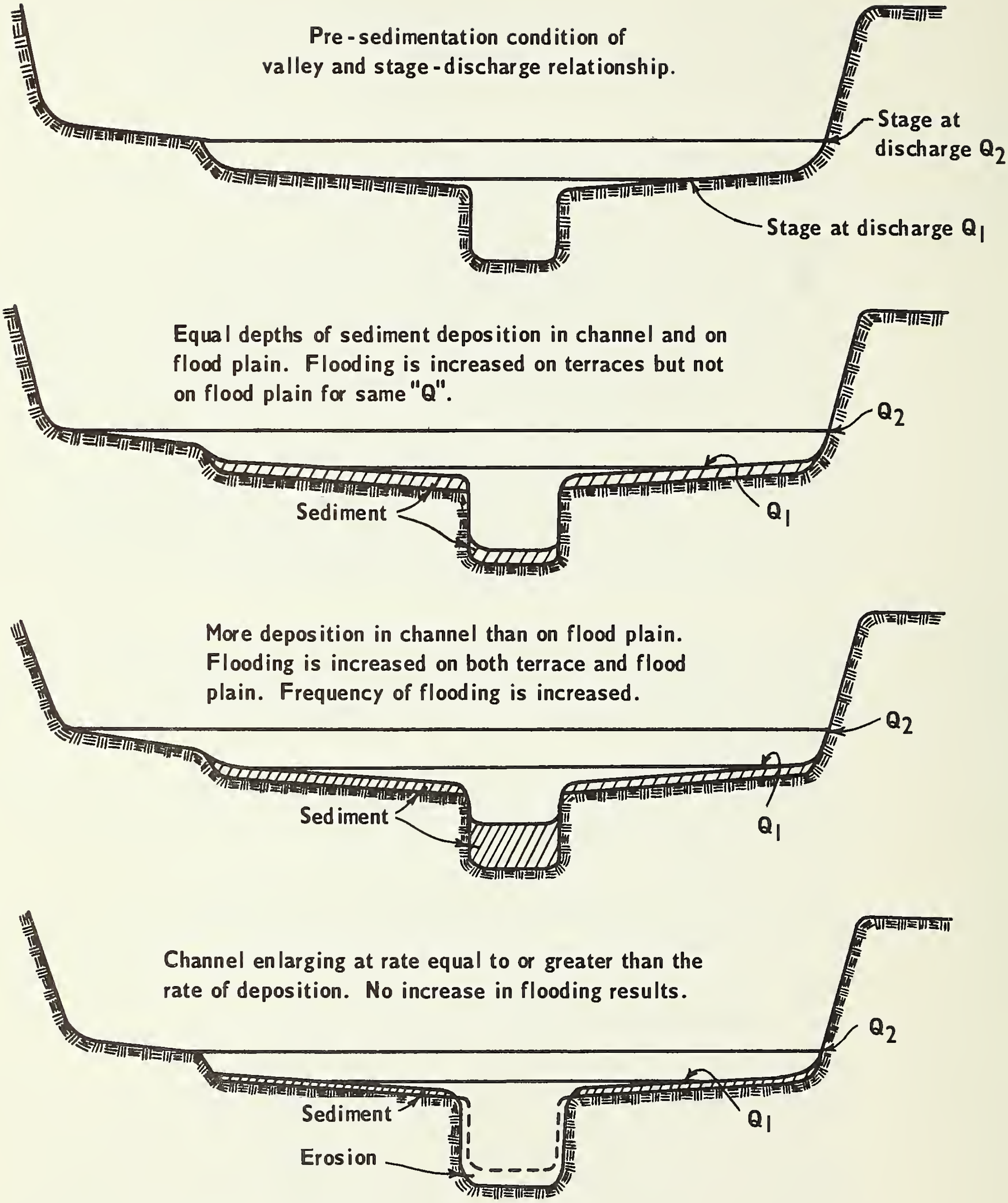


Figure 2-1. Interrelation between Sedimentation and Flood Stages.

Sheet erosion.--Sheet erosion is the detachment of soil particles by raindrop impact and removal by overland flow. Damage is caused by the reduction of productivity of the soil. Although serious damages result from this type of erosion in a watershed, it is not necessary to evaluate these on a monetary basis, since the land treatment measures required for control need no monetary justification.

Flood-plain scour.--This is erosion of the flood-plain surface by flood flows. Two types of scour are recognized: (1) channel scour and (2) sheet scour. Scour channels range from broad, gently sloping, linear depressions which have little effect on farming operations, to incised channels from which much soil has been removed and which cannot be crossed by farm machinery. Sheet scour results in removal of thin layers of soil and is the flood plain equivalent of upland sheet erosion. This type of damage is evaluated on a monetary basis, since it requires other than land treatment measures for control. Channel-type scour tends to recur in the same location and is most common across stream meanders. Flood plain scour damage is evaluated on the basis of reduced productivity of flood-plain soils, land loss and land depreciation.

Streambank erosion.--This is the removal of material of stream channel banks caused by the force of flowing water and the caving of streambanks. Such erosion may also cause damages to bridges, buildings and other structures and to roads and highways.

Gully erosion.--Gully erosion is the removal of upland soil and parent materials and formation of channels by concentrated flow of water. A channel formed in this manner is classified as a gully when it cannot be obliterated by normal tillage operations. Under this definition, rills are not classified as gullies, but would be considered as sheet erosion. Damage by gully erosion results from land loss and land depreciation as well as sediment production.

Valley trenching.--This is the formation and enlargement of a well-defined channel in flood plain or other alluvial deposits. Damage may result in lowering the water table in adjacent bottomlands as well as the loss of land and land depreciation. Severe trenching can also cause active erosion of drainage ditches and tributary channels by lowering their base level of erosion, thus increasing their grades and causing them to cut deeper and migrate headwards.

Stream channel degradation.--This form of erosion is the removal of channel bed materials and downcutting of natural stream channels. Such erosion may initiate degradation of tributary channels causing damages similar to those from gully erosion and valley trenching.

Flood Plain Damage Surveys

Purpose and Objectives

For the purpose of this technical release, a flood plain is defined as an alluvial area adjacent to a stream and subject to overflow during high waters. A flood plain damage survey is used to obtain

physical data regarding the areal extent, rate and degree of damage caused by infertile deposition, swamping, streambank erosion, flood plain scour, valley trenching, and aggradation and degradation of channels.

The major objectives of the flood plain damage survey are to determine:

1. The physical damage to valley soil and other resources and depreciated land values, due to accelerated sedimentation;
2. The physical effect of sedimentation on flood conditions and flood-control problems;
3. The relative importance of various erosional sources as factors in contributing to bottomland damages;
4. The physical facts necessary to evaluate and project the effects of possible sediment-control measures.

In order to attain the major objectives, it will be necessary in most cases to:

1. Measure the depth and areal distribution of modern sedimentary deposits and erosion, and
2. Determine the relative textures and productivity of the modern sediments and of the older, pre-modern sediments.

Types of Deposits

In a valley where modern sedimentation is widespread, natural levees, which usually are the dominant features, may be several feet in thickness. Away from the channel and natural levees the deposits of vertical accretion generally taper gradually in thickness toward the edges of the flood plain. Where sedimentation from tributaries and valley slopes has been rapid, alluvial fans and colluvial deposits overlie the edges of the flood plain deposits. If accelerated depposition in the main channel has been excessive, the channel may have become filled until its bottom elevation rises above the surrounding flood plain. In this case, subsequent flood flows generally follow an entirely different course. In some valleys modern sedimentation has caused substantial damage to the flood plain, but has not formed a continuous valley-wide deposit. Then the study of damaged areas involves identification and interpretation of a series of separate deposits.

Modern sediments deposited upon flood plains and channels can be classified into six genetic types. A knowledge of the type of deposit is needed for extrapolating the extent and character of deposits. This information is important in developing methods of investigation and predicting the extent of future damage under both uncontrolled and controlled conditions. The chief types of channel and flood-plain deposits are described by Happ, Rittenhouse, and Dobson [2]. The following summary is presented as a guide to the identification and evaluation of the common types of deposits occurring in and along flood plains.

Channel fill deposits.--Generally sediment deposits in channels are relatively coarse textured and partly or completely fill formerly normal channels. This type of deposition usually occurs under aggrading stream conditons.

Vertical accretion deposits.--These are deposits from widespread overflows. They are coarser grained and thicker on natural levees and finer grained and thinner away from the channel.

Flood-plain splays.--These are relatively coarse-textured, fan-shaped deposits from overflows channeled through low places, or breaks, in natural levees.

Colluvial deposits.--Linear or sinuous heterogeneous deposits from adjacent slopes which occur on the edges of flood plains at the foot of valley slopes. An estimation of their volume, nature, and rapidity of deposition should be made when investigating the deposits of a valley.

Lateral accretion.--These are channel deposits, mostly on the insides of bends accompanying channel migration. They are not important areally.

Channel lag.--Such deposits are relatively coarse textured and constitute a large part of a channel-bottom deposit, especially if the channel is subject to accelerated deposition. These deposits represent residual materials associated with normal stream action and are distinct from channel fill materials in that they do not indicate channel aggradation.

Associations of the Genetic Types of Deposits

The various types of deposits are usually found in characteristic association with each other. In the study of accelerated stream and valley sedimentation, the sediment deposits can usually be grouped into four associations. These are summarized below.

Normal flood plain association.--In the normal flood plain association of sediments, vertical accretion deposits cover coarser deposits of lateral accretion and channel fill. The vertical accretion deposits cover the flood plain with a fairly uniform thickness of fine sediments sloping down valley and away from the channel to the valley sides. Modern channel fill and lag deposits occur in the present channel and in abandoned channels. In the latter case they may be covered by vertical accretion deposits. Sand splays occur immediately alongside present or former channels and interfinger into the vertical accretion deposits. Colluvial deposits interfinger into the vertical accretion deposits from the valley sides. The characteristically low area between the natural levees and the colluvial deposits is called the back swamp part of the flood plain. The characteristics of the different types of deposits in the normal flood plain association are summarized in Table 2-1.

Alluvial fan association.--Alluvial fans are better known by their surface form than by the nature of the deposits composing them. The deposits are typically formed where the gradient of a stream is abruptly lessened, such as when a stream enters the valley of a longer stream.

Channel filling, and vertical and lateral accretion are the chief genetic types represented in alluvial deposits. They are usually so intimately intermixed that there is little systematic surface or areal distinction between them.

Valley-plug associaton.--Valley-plug deposits are associated with filling of the stream channel. As the channel fills at a given place, usually due to decreasing capacity of the channel downstreamward or excessive delivery of sediment from a tributary, the deposits progress upstream by back-filling.

The water is forced overbank and drains down valley through the back swamp area until it can again collect into a definite channel. Valley plug deposits may also result from artificial causes such as ditches emptying into unimproved channels of less capacity or from other causes such as log jams or fallen trees.

Delta association.--Deltas are composed of the subaqueous and subaerial deposits formed when a sediment-laden stream enters a body of comparatively quiet water. The subaqueous deposits are not part of the valley deposits unless they are contained in a stream channel. The subaerial top-set beds merge upstream with the valley flood plain sediments. The subaerial deposits are similar to valley-plug areas and have the same associations of the genetic types of sediments.

Identification of Modern Sediment

Identification of deposits formed by modern accelerated deposition is based chiefly upon proper distinction between modern sediment and the buried original flood-plain soil. Since the characteristics of both the sediment and the buried soils are different in different valleys, these relationships must be investigated when beginning a valley survey. A list of important criteria, upon which distinctions can be based follows:

Texture.--Modern sediment is coarser, in most cases, with a greater range in texture, whereas buried soil is usually finer with more uniformity in texture.

Color.--Modern sediment is generally a lighter color which may vary with texture, whereas buried soil is generally darker and more uniform.

Compaction.--Modern sediment is less compact and less cohesive, whereas buried soil is more compact and cohesive.

Table 2-1. Characteristics of Genetic Types of Valley Deposits

Basis of Comparison	Types of Deposits					
	Colluvial deposits	Fluvial deposits				
		Vertical accretion deposits	Splay deposits	Lateral accretion deposits	Channel-lag deposits	Channel-fill deposits
Principal origin	Concentration by slope wash and mass movements	Deposition of suspended load	Deposition of bed load	Deposition of bed load always prominent, but suspended load may be dominant	Deposition of bed load	Deposition of bed load and suspended load
Usual place of deposit	At junction of flood plain and valley sides	On entire flood-plain surface	On flood-plain surface adjacent to the stream channel	Along side of channel especially on the inside of bends	On channel bottom	Within the channel
Dominant texture	Varies from silty clay to boulders	Dominantly silt; often sandy, especially near channel; often much clay	Usually sand; may be gravel or boulders	Sand or gravel; may include silt or boulders	Sand, gravel, and boulders	Usually sand, silt, and gravel; may include clay or boulders
Relative distribution in the valley fill	Interfinger with the fluvial deposits along outer margins of flood plain	Overlie deposits of lateral accretion and channel deposits; overlain by or interbedded with splay and colluvial deposits; usually cover most of flood-plain surface	Form scattered lenticular deposits overlying or interbedded with vertical accretion deposits adjacent to present or former channels	Usually overlain by vertical accretion deposits, often underlain by channel-lag or channel-fill deposits; may extend across entire flood-plain width	Underlie channel-fill or lateral or vertical accretion deposits; either as a nearly horizontal stratum, a veneer lying on the bedrock floor, or in linear channel beds	Usually from elongate deposits of relatively small cross section, winding through flood plain; may overlie lag deposits and underlie vertical accretion deposits

Distinctive minerals.--Modern sediment may contain grains of micas, gypsum, feldspars, calcite or other easily weathered minerals, whereas very few grains of easily weathered minerals are contained in buried soil. Buried soil usually contains an abundance of clay minerals.

Evidence of cultural activity.--Modern sediment may cover or contain buried boards, tools, bricks, fences and other man-made objects, and buried tree stumps.

Stratification and water table relationships.--In many cases modern sediment has distinct stratification with cross-bedding and lenticular beds. A perched water table, supported by the old soil, may be in the sediment deposit.

Field Procedures for Determining Flood-Plain Damages

Preliminary Sedimentation Investigation

Where field inspection indicates that appreciable floodwater erosion and sediment damages occur and need to be determined for work plan development, more intensive investigations will be required.

The first step in evaluating all areal sedimentation and erosion damages is a preliminary sedimentation investigation. The preliminary investigation will be planned to establish the general extent and nature of sedimentation and erosion damage in the area considered, the approximate limits of sub-areas within which conditions are essentially alike, and to select representative sample areas within that problem region for detailed investigation. It should also include a determination of whether location, rates, and kinds of deposition in a portion of, or throughout the flood plain, represent present conditions or whether measurement will fail to reflect substantial recent changes in the watershed. These changes may be large increases or decreases in channel capacity or sediment supply by natural or artificial means. The location and interpretation of detailed flood plain sedimentation surveys should conform with these determinations.

The preliminary investigation will also include inquiry and search for any available survey records which may be suitable for comparison with present conditions to measure rates of channel or valley aggradation, or harbor filling. Such survey records may be highway or railway bridge cross sections, or surveys for navigation, levee construction, drainage, irrigation, or other engineering purposes.

The preliminary investigation involves the traverse of representative parts of the area and examination of valley conditions. Test borings and examinations of stream-cut banks and other exposures showing the vertical sequence of flood-plain deposits should be made. The size and condition of stream channels; nature of channel sediment; soil texture; land use; apparent productivity of agricultural land; surface indications of rates of sedimentation, such as buried fence posts and trees; and types of sediment damage and percentage of land involved in each type will be recorded at each place where valley conditions are

examined. Random test borings will usually be required at numerous places. The sources of harmful sediment should be determined by inspection of eroding areas and qualitative comparison with sediment deposits causing damage.

Inquiry should also be made among local residents and land owners, and among public officials and other informed persons for any pertinent information that will show rates of sedimentation, extent and nature of associated damages, or location of areas of particularly rapid or harmful deposition.

Detailed Sedimentation Investigations

Development of plan.--When the preliminary sedimentation investigation indicates that the sediment damages are of sufficient importance to justify detailed investigation, a plan for such further investigation should be developed. This plan should specify the types of investigations needed and the approximate personnel and time required. It should include either a sketch map showing generalized or tentative distribution of boring ranges, sampling-survey areas, and other work areas, or summarized lists of areas to be surveyed in detail and approximate numbers of ranges to be bored, and cross sections to be profiled.

Boring and logging.--Thickness and distribution of the modern deposits are usually major factors determining the nature and extent of sedimentation damage. Therefore, it is necessary to measure the existing modern sedimentary deposits as a basis for estimating past damage, and predicting future rates and trends of sedimentation and sediment damage. In the case of valley deposits, this is done by making test borings at selected locations for measurement of the thickness of modern deposits, and by measurement of surface elevations.

The exact location of test borings is decided in the field, in order to obtain optimum working conditions and avoid locations where, because of local conditions, identification of the thickness of modern deposits might be especially difficult. Borings must be so located as to show the major changes in slope of the base of modern deposits, such as those at the base of pre-modern valley sides bordering the flood plain, and any flood-plain terraces which may have been buried by modern deposition.

The record should include pertinent information such as the texture, color, presence or absence of concretions or other inclusions, depth of water table, relative acidity, presence or absence of organic matter. These data may be obtained by 4-inch samples. Longer or shorter samples may be used in homogeneous beds in which no marked changes in the sediment characteristics are noted. For each hole, the depth of the base of the modern deposits will be indicated in the notes, according to the best judgment of the recorder in the field. The records of boring may be kept either in a loose-leaf type notebook or on standard logging form SCS-533. Notes should include the date,

the identification numbers assigned to each range and each hole on a range, the approximate spacing and direction of numbering of holes, the location of stream banks relative to the nearest adjacent holes. Notes also should include the distance from the outer margins of flood-plain deposition to the nearest boring holes, the approximate location and magnetic direction of the range, and a field location sketch.

Interpretation of damage surveys.--The degree of damage to flood-plain areas is usually determined from the boring data. The percent of damage is estimated, usually to the nearest 10 percent in terms of productive capacity of the original soil. This is done by determining the depth and texture of the deposited sediment and estimating the loss. As the depth of the sediment increases and its texture becomes coarser and/or less productive, the extent of damage increases. If the original soil was a highly productive silt loam, high in organic matter and other available plant nutrient, the damage by relatively infertile sands is considered to be high. The same type of sediment deposited to the same depths on an original sandy soil which was low in organic matter, nitrogen, phosphorous and potash, would result in a lesser damage. In this instance the recovery period of the new sediment to the original soil condition would be shorter and the remaining damage would be lower.

Other means of determining the present percent of damage are: (1) a comparison of crop yields on land which has suffered deposition with crop yields on similar land which has received no deposition, and (2) interviews with owners or operators who may be able to furnish information on reduction in their crop yields resulting from deposition.

In addition to the estimates of damage, the rate of recovery under flood-free conditions is estimated as illustrated in Table 2-2.

In general, the areas of higher damage require longer periods of time for recovery. Also, full recovery normally will not occur when the present damage is 40 percent or higher. It should be emphasized that estimates of recovery must be based largely on judgment, keeping in mind that both damage and recovery will vary according to the type of soil on which the damage occurs, and the sediment deposits.

Channel-erosion surveys.--Determination of channel erosion may be required to evaluate land loss and land depreciation damages; and/or to obtain information on sources of harmful sediment. In obtaining information for evaluating land loss and land depreciation damages, it is important to know the area of land being eroded, or voided. In respect to sources of harmful sediment, the volume and, therefore, the depth of erosion as well as the area of erosion must be known. Sampling of channel materials is often necessary if sediment damages are due to specific grain sizes so that the volume of the specific or critical, sediment sizes can be determined.

Table 2-2. Percentage of Damage to Flood-Plain Lands and Estimated Recovery as Related to Depth and Texture

Depth and Texture		Damage	Recovery Period	Damage remaining after recovery
		Percent	Years	Percent
4- 8"	Fine and coarse sand and silt	20	5	0
4- 8"	Med. and coarse sand	40	10	10
8-12"	Fine and coarse sand	40	10	10
12-14"	Coarse sand	60	20	30
12-24"	Coarse sand and gravel	90	30	50

The intensity and degree of accuracy of investigations for channel erosion depends upon the nature of erosion, the extent of damage involved and the purpose of the survey. In cases where streambank erosion is an important factor in the sedimentation problem, either because it is associated with sedimentation damage or because it must be evaluated as a source of harmful sediment, special bank erosion surveys are necessary. These include field mapping of the lengths of streambank subject to active erosion with estimates of the rates of erosion, and direct measurements of the amount of cutting within known periods of time wherever it is possible to get records of former channel width or bank position at specific locations as a basis for comparative resurveys. Aerial photographs should be used if they are available. Resurveys, if necessary, may be by planetable mapping, stadia measurement, chaining, or pacing, according to the accuracy justified by the data with which comparison is to be made and the importance of the problem involved. In most cases, pacing will be a sufficiently accurate measurement of the amount of bank erosion removal, but if it is necessary to locate the position of former channel banks for comparative purposes, chaining or planetable mapping may be necessary. The data required will usually include length and average height of eroded banks, and width of the area or strip eroded during the period under consideration.

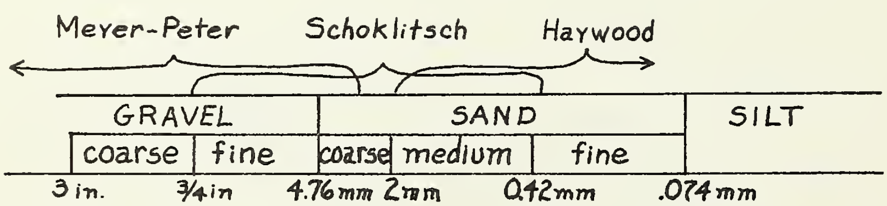
Where the bank erosion consists of numerous short stretches of eroding banks, measurements should be confined to representative sample reaches which can then be extrapolated to determine erosion for the entire reach. Where erosion is occurring along different types of banks, the classification of banks together with intensities of erosion is necessary. For example, if a reach contains alternately eroding high clay banks and low gravel banks, the rate of recession and volume of eroded material produced will be different so that the rates of each

type must be determined separately to extrapolate the total damage area or sediment volume for the entire reach.

Valley trenching can create severe land loss and land depreciation damages to valuable flood-plain lands. Where such damages must be evaluated, special attention and survey procedures are to be used. These are outlined in detail in a separate technical release [3]. Briefly the procedure requires a determination of the past, or historical rate, of gully development which is adjusted to the future expected rate on the basis of transitory changes in the contributing drainage areas, slopes of approach channels above the advancing head, the rainfall characteristics and erodibility of materials through which the head is advancing. Where valley trenching is of concern only from the standpoint of volume of sediment produced, the procedures applicable to determining streambank erosion are also applicable to valley trenching.

The areas of flood plain scour pits can often be determined by pacing. Normally, the area is not determined directly for flood-plain scour unless only a single, very large, or a very important, scour pit exists on the flood plain. Generally scour pits are small and widely scattered, and their areas determined on a sampling basis along valley ranges.

The depth of most types of channel erosion, such as streambank and valley trenches can readily be measured in the field. However, it is sometimes necessary to predict future ultimate depths of channels, such as in valley trenching or stream channel degradation. In such instances particular attention must be given to the character of materials in respect to channel flows. Estimates of erosion occurring in the beds of streams composed of noncohesive materials may be made by the method outlined on page 6-23 through 6-43 of Technical Release No. 25 [13] or by the use of the following equation. These equations are keyed to the size of the principal material comprising the bed. Particle size classifications are those used in the Unified Soil Classification System. The formula name and the size range which they cover are shown in the following sketch:



Following are the formulas to use for the foregoing ranges of non-cohesive materials:

$$\text{Meyer-Peter} \qquad Gs = (Aq^{2/3}\,S - B\,d_m)^{3/2}$$

$$\text{or} \qquad Gs = (39.25q^{2/3}\,S - 9.95\,d_m)^{3/2}$$

$$\text{Schoklitsch} \qquad Gs = A\,\frac{S^{3/2}}{d^{1/2}}\,(q-qc)$$

$$\text{or} \qquad Gs = 86.7\,\frac{S^{3/2}}{d^{1/2}}\left(q - 0.00532\frac{d}{S^{4/3}}\right)$$

$$\text{Haywood} \qquad Gs = \frac{(q^{2/3}\,S - A\,d^{4/3})^{3/2}}{B\,d^{1/3}}$$

$$\text{or} \qquad Gs = \frac{(q^{2/3}\,S - 1.2\,d^{4/3})^{3/2}}{0.117\,d^{1/3}}$$

Where:

A and B are constants of differing values for the various formulas.

Gs = bedload transport in pounds per second per foot of average channel width

S = hydraulic gradient in feet per foot

d or d_m = representative diameters of bed material expressed in the following units of measure depending on the equation used:

Meyer-Peter - d_m in feet 1/
Schoklitsch - d_{50} in inches
Haywood - d_{35} in feet

q = discharge in cfs per foot of average channel width

qc = "critical" discharge - the discharge in cfs per foot of average channel width at which bed material starts to move.

The following field information is required to solve each problem:

a. The reach of stream to be rated must be selected.
b. Cross sections of the channel and valley referenced to a common datum must be obtained.
c. The bed and/or bank material must be sampled and analyzed.
d. The slope s of the reach must be determined.
e. The hydraulic and hydrologic information for the reach must be developed.

1/ In Meyer-Peter d_m = mean grain size of bed material from which the material smaller than d_{35} has been omitted.

Estimating sediment volume from relatively recent channels such as valley trenches and gullies occurring in cohesive materials should be done by projecting the past rate to the future providing that land loss and land depreciation damages are not being evaluated. For unusual cases where it is desired to determine the volume of sediment being eroded from seasoned channels, such as stream channels in cohesive materials, special procedures must be used. In this event the field geologist should confer with the EWP Unit geologist to select a suitable method.

Sampling of materials.--Where the texture of sediment is an important consideration such as in determining sources of sediment from channel erosion, or, in channel stability determinations, it will be necessary to obtain samples for laboratory analysis.

The important consideration in this respect is that the materials sampled be representative of the materials in which future erosion will occur. Thus, it may be necessary, sometimes, to obtain samples from bore holes rather than from the existing channel walls if there is a significant difference in the texture of materials. Disturbed samples of coarse materials can often be obtained, screened, and weighed in the field at less cost than bagging and shipping the samples to the laboratory for analysis. All samples of undisturbed materials and all fine-grained materials normally would be sent to the laboratory to be analyzed. Instructions for sampling, packaging samples and for transmittal to the Soil Mechanics Laboratory for analysis are contained in Chapter 3, Section 8 of the National Engineering Handbook [4].

Methods of flood-plain survey.--To obtain an estimate of damages in the most usable form, it is necessary to divide the flood-plain area into reaches. The division of the flood plain into reaches should be done in cooperation with other members of the planning party since the geology, economics, hydrology, and hydraulics must be related to a common base. Fundamentally, each reach should be as homogeneous as possible.

There are two methods of obtaining the amount of flood-plain damage on each reach: the mapping method and the range method. The mapping method is used when deposition or erosion is concentrated in limited and scattered areas. Where deposition or erosion are generally distributed within the valley, the range system of survey provides more representative sampling. Similar results are obtained by both, provided a high degree of accuracy and consistency in sampling damage evaluation has been developed by each person engaged in the flood plain damage study and selected ranges are representative. Adaptations of these methods or the development of additional means of determining sediment and related damages to flood plains may be made in consultation with the EWP Unit geologist. Estimates should be developed in consultation with specialists of the SCS, representatives of cooperating agencies, and local residents.

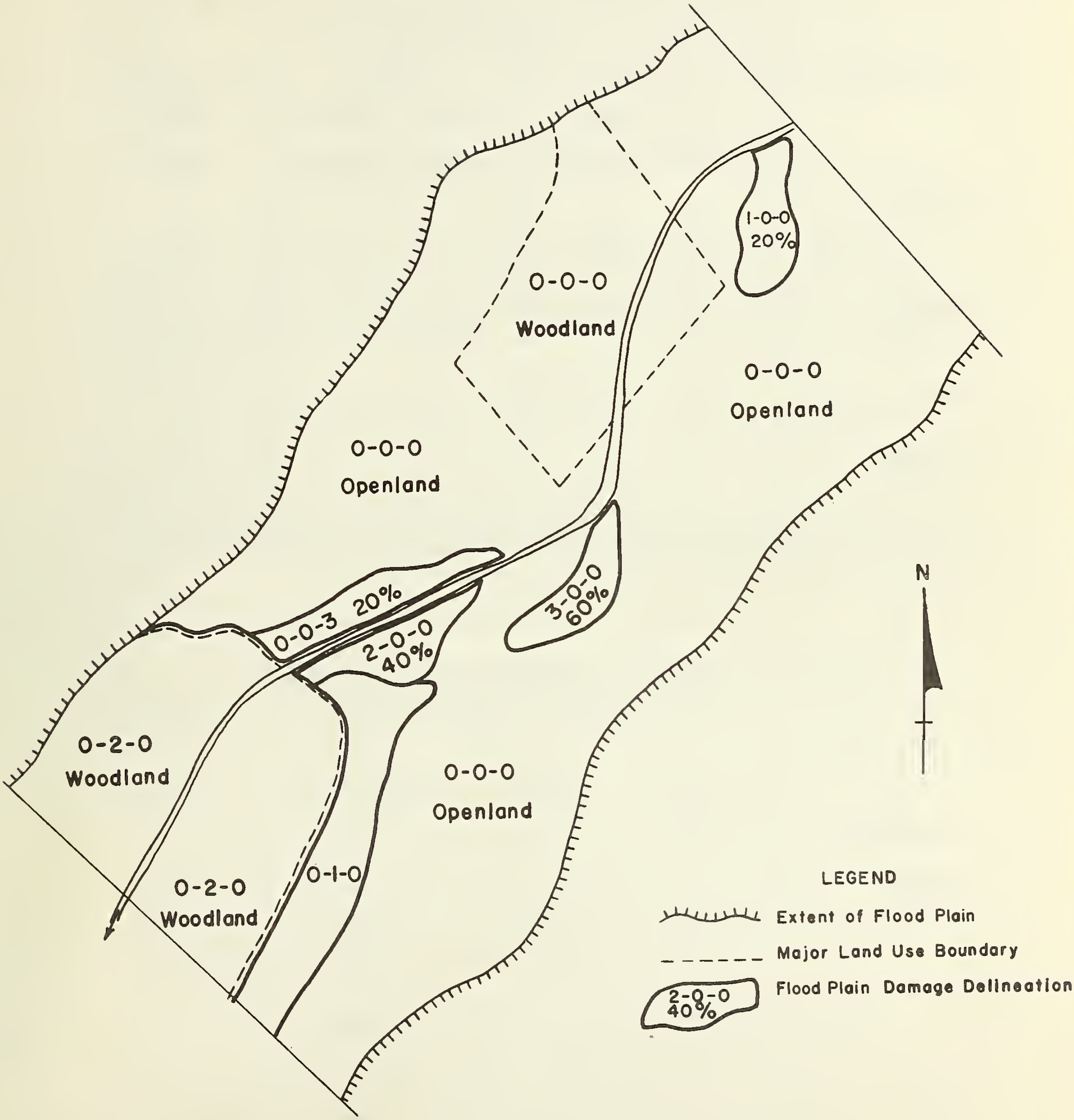


Figure 2-2. Flood Plain Damage Survey-Reach B.

Table 2-3. Acreages and Damages by Various Land Use Delineations

Type of Damage	Major Land Use: Openland Area	Openland Damage	Woodland Area	Woodland Damage	Channel Area
	Acres	Percent	Acres	Percent	Acres
Deposition					
1	7	20	--	--	--
2	7	40	--	--	--
3	6	60	--	--	--
Swamping					
1	23	--	--	--	--
2	--	--	77	--	--
Scour					
3	8	20	--	--	--
No Damage	300	--	50	--	11

A summary of weighted sediment damage (by area) to the flood plain in Reach B shown in Figure 2-2 is shown in Table 2-4. This summary can be turned over to the economist for monetary evaluation.

Table 2-4. Summary of Flood-Plain Damages - Reach B

Type of Damage	Area	Period	Rate	Damage
	Acres	Years	Acres/Year	Percent
Deposition ...	20	--	20	38
Swamping				
1	23	40	0.6	1/
2	77	40	1.92	1/
Scour	8	--	8	20

1/ To be determined in consultation with the economist

Insofar as practical, the flood-plain ranges should include the surveyed cross sections used for hydrologic study. Where they are the same, many of the distance measurements may be obtained from the plotted cross sections. As a word of caution, the hydrologist needs cross sections at control points. These may not be typical of flood plain conditions. Where the ranges are independent of these cross

sections, it will be necessary for the geologist to pace the distance, or preferably, to obtain distance by using an aerial photograph as a base map. A minimum of 4 holes will usually be required on each range. Generally the spacing will be from 100 to 300 feet between holes, for valleys 1 mile or less in width. The geologist must show the lineal extent of each type of damage along each range. At the same time, the degree (in percent) of the damage is recorded.

All data are recorded on a field sheet as shown in Table 2-5. A separate sheet is prepared for each range.

In summarizing the data for the flood plain, it is first necessary to summarize the data on each field sheet. This might be done on a weighted average basis or by individual increments depending on the nature of the data desired by the economist. Following is an example for summarizing data for damages by infertile deposition on a weighted average basis.

	100	lineal	feet	damaged	10	percent	by	infertile	deposition
	100	"	"	"	20	"	"	"	"
	50	"	"	"	90	"	"	"	"
Total: for Range:	250	lineal	feet	damaged	30	percent	by	infertile	deposition

Other types of flood plain damage can be summarized much the same way.

In the foregoing summary it is seen that the distance of 250 feet is damaged by infertile deposition. The weighted average damage is 30 percent, i.e. $\frac{(100x10) + (100x20) + (50x90)}{250} = 30\%$

The next step is to summarize the damage within each reach. This is most easily accomplished by using a field summary sheet. A separate summary sheet is used for each reach and the "Totals and weighted averages" computed for each individual range are itemized in the columns. The columns are summarized, following the procedure used to summarize individual ranges, to obtain an average range for each reach of flood plain. See Table 2-6 for an example. Table 2-7 shows a method of computing average values for a reach.

Table 2-5. Sample Work Sheet for Summarization of Range Data

Range 1 Reach A

Mud Creek Watershed Survey

From Station to Station 1/		0-100	100-120	120-220	220-240	240-260	260-310	310-End	Totals and Weighted Average
Infertile deposition	Distance (Ft.)	100	--	100	--		50	--	250
	Percent Damage 2/	10	--	20	--		90	--	30
Swamping	Distance (Ft.)	--	20	--	--		--	--	20
	Damage (%)	--	40	--	--		--	--	40
Streambank erosion	Distance (Ft.)	--	--	--	.20		--	--	20
	Damage (%)	--	--	--	90		--	--	90
	Average depth (Ft.)	--	--	--	3		--	--	3
	Net X-Sectional Area(Ft^2)	--	--	--	60		--	--	60
Flood plain scour	Distance (Ft.)	--	--	--	--	Mud Creek Channel	--	--	--
	Percent Damage	--	--	--	--		--	--	--
	Average Depth (Ft.)	--	--	--	--		--	--	--
	X-Sectional Area (Ft^2)	--	--	--	--		--	--	--
Valley trenching	Distance (Ft.)	--	--	--	--		--	--	--
	Damage (%)	--	--	--	--		--	--	--
	Average Depth (Ft.)	--	--	--	--		--	--	--
	X-Sectional Area (Ft^2)	--	--	--	--		--	--	--
Land use	Original	Corn	Corn	Corn	Corn		P	--	--
	Present	Corn	Idle	Corn	Idle		P	--	--
Texture	Gravel (%)	--	--	--	80		60	--	--
	Sand (%)	--	--	--	10		40	--	--
	Fines (%)	100	100	100	10				

1/ All measurements from left side of valley looking downstream unless otherwise noted.
2/ To nearest 10 percent.

Table 2-6. Example of Work Sheet for Computation of Weighted Average of Reach Damage--Reach A

1 Type of Damage	2 Distance Feet	3 Damage Percent	4 Damage Factor (Col's 2x3)		5 Averages
Infertile Deposition	250	30	7,500		(av. distance)
	210	30	6,300		$\frac{1,110}{5}$ = 222 ft.
	260	20	5,200		
	210	40	8,400		(av. damage)
	180	40	7,200		$\frac{34,600}{1,110}$ = 31%
	1,110		34,600		
Swamping	20	40	800		(av. distance)
	150	30	4,500		$\frac{232}{5}$ = 46.4 ft.
	35	50	1,750		
	27	40	1,080		(av. damage)
	232		8,580		$\frac{8,130}{232}$ = 35%
Streambank Erosion				(Area)	
	20	90	1,800	60	(av. distance)
	18	90	1,620	72	$\frac{125}{5}$ = 25 ft.
	35	60	2,100	105	
	32	80	2,560	128	(av. damage)
	20	80	1,600	80	$\frac{9,680}{125}$ = 77%
	125		9,680	445	
					(av. area)
					$\frac{445}{5}$ = 89 sq/ft
					(av. depth)
					$\frac{18}{5}$ = 3.6 ft.
Scour	0	0	0		(av. distance)
	0	0	0		$\frac{36}{5}$ = 7.2 ft.
	0	0	0		
	10	60	600		(av. damage)
	26	60	1,560		$\frac{2,160}{36}$ = 60%
	36		2,160		
Scour Depth				(Area)	(av. depth)
	0	0		0	$\frac{82}{36}$ = 2.3 ft.
	0	0		0	
	0	0		0	(av. cross sec.)
	10	3*		30	$\frac{82}{5}$ = 16.4 ft.^{2}
	26	2*		52	
	36			82	

* Depth in feet

Table 2-7. Sample Work Sheet for Summarization of Reach Data

Reach A Summary

Mud Creek Watershed Survey

From Station to Station 1/		Range 1	Range 2	Range 3	Range 4	Range 5	Total	Average
Infertile deposition	Distance (Ft.)	250	210	260	210	180	1110	222
	Damage (%)2/	30	30	20	40	40		31*
Swamping	Distance (Ft.)	20	150	0	35	27	232	46.4
	Damage (%)	40	30	-	50	40		35*
Streambank erosion	Distance (Ft.)	20	18	35	32	20	125	25
	Damage (%)	90	90	60	80	80		77*
	Average Depth (Ft.)	3	4	3	4	4		3.6
	Net X-Sectional Area (Ft.^{2})	60	72	105	128	80		89
Flood plain scour	Distance (Ft.)	0	10	0	26	0	36	7.2
	Damage (%)	--	60	--	60	--		60*
	Average Depth (Ft.)	--	3	--	2	--		2.3*
	X-Sectional Area (Ft^2)	--	30	--	52	--		16.4
Valley trenching	Distance (Ft.)	--	--	--	--	--		--
	Damage (%)	--	--	--	--	--		--
	Average Depth (Ft.)	--	--	--	--	--		--
	X-Sectional Area (Ft^2)	--	--	--	--	--		--
Land Use	Original	W3/	C3/	C	C	C		--
	Present	W	P3/	P	P	P		--
Texture	Gravel (%)	0	0	0	0	0		--
	Sand (%)	80	95	95	95	95		--
	Fines (%)	20	5	5	5	5		--

1/ All measurements from left side of valley, looking downstream, unless otherwise noted.
2/ To nearest 10 percent
3/ C = cropland, P = pasture, W = woodland
* Weighted Average

The computed damage is then expanded to the area of the reach. If the flood-plain area is available from maps or aerial photographs, the average range length is divided into the area of the reach to obtain a valley length factor in acres per foot of width. This figure multiplied by the average width damaged on the ranges, gives the area damaged in the reach. Following is an example of how the area damaged by infertile deposition can be tabulated:

1	2	3	4	5	6	7
Reach	Area of Reach	Average range length	Valley length factor (Col.2/Col.3)	Average width damaged	Area damaged (Col. 4 x Col.5)	Reach damage (Col.6÷Col.2 x 100)
	Acres	Feet	Acres/Foot	Feet	Acres	Percent
A....	432	714	.605	222	134	31

If the area of the reach is not known, the mileage of stream valley in each reach should be measured using large scale maps or field surveys. The acres of flood plain damaged to date by each type of damage in each reach can then be determined from the following formula:

$$a = 0.121\ bc$$

where a = acres damaged to date
b = lineal distance damaged on the average range, in feet
c = length of stream valley in this reach, in miles

0.121= a conversion factor ($\frac{5280 \text{ ft/mi}}{43560 \text{ ft}^2\text{/ac}}$) to convert "b" in feet and "c" in miles to acres.

This procedure also lends itself to tabulation as seen in the following tabulation of damage data by reach:

1	2	3	4	5	6	7
Reach	Valley length (c)	0.121 c (0.121 x Col.2)	Average width damaged (b)	Area damaged (a) (Col.3 x Col.4)	Area of reach	Damage
	Miles	Acres/foot	Feet	Acres	Acres	Percent
A....	5	.605	222	134	432	31

By these methods a determination may be made of the present condition of the flood plain. It is important that the physical data be complete and usable by the economist.

Determining Average Annual Flood-Plain Sedimentation and Erosion Damages

Flood-Plain Deposition and Scour Damages

General considerations.--Physical damage figures provided to the economist for monetary evaluation should be reduced to average annual values. To project the historic average annual rate of damage to future rate of damage it must first be determined whether the present rate of damage is in equilibrium, is increasing, or is decreasing. This information must also be supplied to the economist in order for him to properly evaluate future damages with and without the project installed. The geologist should work closely with the agronomist and soil scientist in determining physical damages due to loss in productivity.

Equilibrium damages.--In this case new damage by deposition or scour occurring each year is offset by recovery of old damaged areas. When such a condition exists the benefits to be derived will be the result of reducing the annual rate of damage so that the equilibrium point will be shifted in the direction of less loss of income. The geologist determines the total area damaged and the loss of productivity. He also estimates the portion of the damage that could be expected to recover were it no longer subjected to flooding or deposition.

Increasing damages.--The damage may be increasing in area or in severity or both. In such instances, the geologist will provide the economist an estimate of the existing rate of damage and the rate at which the damage is increasing, plus an estimate of the eventual limits of the damage, such as the total area that may be affected.

Decreasing damages.--Recovery of damaged areas may be taking place under present conditions with the damage decreasing in areal extent or in severity. In these instances, the geologist will furnish the economist an estimate of the existing rate of damage and the rate at which the damage is decreasing, plus an estimate of the acreage that will be subject to damage after the limits of such decrease are reached.

Channel Erosion Damages

One method for reducing the total observed linear channel erosion to an average annual value is to compare the observed amount, as recorded on the field sheets, with an average annual value as determined by surveys or by aerial photographs made at different dates.

Since earlier flood plain cross sections from engineering surveys are seldom available, it is convenient to substitute aerial photographs of

different dates. It is necessary to locate control points that are common to each set of photos and carefully measure the change in position of the eroding bank in relation to these fixed points. A large number of measurements are necessary. The average distance of channel wall movement between the photograph dates is reduced to an average annual value by straight division.

$$\frac{\text{Distance}}{\text{years}} = \text{average annual distance}$$

The average annual distance, in this case, is the past historical rate. This value is normally suitable for estimating rate of land loss and land depreciation from streambank erosion. However, in respect to valley trenching with serious damages where the headcut, during the economic evaluation period, will advance into topographically or geologically different materials, or, the drainage above the advancing headcut will become significantly reduced in area, adjustment should be made in accordance with established procedures [3].

In determining damages from lateral movement of channel walls the actual area eroded, or voided, must be determined and the area depreciated. The future rate of damage may have little bearing on the past rate even though the physical rate may have been the same. An example might be a valley trench which in the past may have progressed through relatively low value land, while the advancing headcut in the future might engulf more valuable property such as farmsteads, bridges, orchards, etc. in its path. Thus, the direction of channel erosion as well as the rate becomes an important element in evaluating damages from channel erosion.

In computing physical damages by channel erosion, the geologist determines the annual rate of surface acreage of land actually eroded, or voided. This information is provided to the economist. The geologist and economist work closely together to determine the area of land to be depreciated. In this connection consideration is given to effects of channel erosion on tillage operations, ground levels, isolating farm fields, and other damages that can be evaluated.

Swamping Damage

Swamping damage is treated as an incremental or increasing damage. Therefore, a rate of swamping in acres per year must be established.

The area of presently swamped land is obtained from the flood plain survey. The period of time during which this damage occurred must be determined through local interviews. The area of swamped land divided by the time will give the average annual rate of swamping damage in acres per year. It is this rate that can be reduced or alleviated by a watershed program, thus, obtaining benefits.

It must be established that there is land in the flood plain that is still subject to damage by swamping. Benefits of the program on lands damaged 100% by swamping are treated as restoration to former use or as enhancement.

All information developed from the flood plain survey may be summarized in tabular form similar to Table 2-8.

Table 2-8. Flood Plain Damage Summary - Reach A

Type of Damage	Average length of range damaged	Area	Damage	Recovery Period	Damage Remaining After Recovery
	Feet	Acres	Percent	Years	
Infertile deposition	222	134	31	10	0
Swamping	46.4	26.9	37	15	10
Streambank erosion	25	15	77	0	--
Scour	7.2	4.4	60	0	--
Valley trenching	--	--	--	--	--

Reservoir Sedimentation Surveys

Purpose

Reservoir sedimentation surveys are made in work plan development to evaluate sediment damages to a specific reservoir, or to obtain sediment yield data for a watershed where existing data are either lacking or inadequate for work plan purposes.

All sediment yield data applicable to the problem area in which the watershed is located should be assembled and analyzed prior to the planning and initiation of any reservoir sedimentation survey. Information on existing reservoir sedimentation surveys and inventories of sediment load measuring stations are contained in publications of the Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources [5] [6] [7] [8]. Additional published and unpublished sediment yield data may be available in the records of the Engineering and Watershed Planning Units.

Sedimentation surveys of reservoirs for evaluating sedimentation damages are not necessarily limited in respect to size of drainage area. The selection of reservoirs for survey depends upon the seriousness of sediment damage; whether or not the watershed under consideration is the source of all, or a major part, of the sediment contributing to the damage, and whether or not the proposed watershed protection program will have an appreciable effect in reducing such damages.

An investigation should be made in the field before final selection is made of the reservoir or reservoirs to be surveyed. This should include an inspection of the watershed above the structure to assure that land use and topography are representative of the watersheds to which the data will be applied. Trial spuddings should be made prior to final selection in order to determine whether modern sediment can be readily distinguished from pre-reservoir materials, and to determine types of equipment needed for making a detailed survey.

Interviews should be held with owners and local residents to determine the history of the reservoir and the reliability of results which would be obtained by a detailed survey. Thus, if the dam had been breached during its history, or if an unknown amount of sediment was dredged or otherwise removed from the reservoir, the measured deposits would not provide a reliable measure of the sediment yield. Interviews with owners and local residents also provide information on availability of boats, motors, and other equipment which may need to be acquired to carry out a survey.

Detailed Reservoir Surveys

Two methods of survey may be used--the contour method or the range method. Exept on rare occasions, the range method of survey is best adapted to watershed planning investigations. Details of equipment, field methods, and computations have been outlined by Eakin and Brown [9] and by Gottschalk [10] and in Technical Release No. 22 [11].

Reporting Results

Upon completion of the reservoir sedimentation survey and computation of results, the results should be summarized in convenient form for future reference. Form SCS-34 (Rev. 6-62), "Reservoir Sediment Data Summary," is available with instructions for filling out this form. This form was developed by the various Federal agencies represented on the Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources, to facilitate the collection and dissemination of sediment yield data. A completed copy of this form should be sent to the Engineering and Watershed Planning Unit to be incorporated in a national summary.

Evaluation of Reservoir Sedimentation Damages

Methods of Evaluation.--There are four general methods for evaluating reservoir sedimentation damages: (1) straight-line, (2) sinking fund, (3) sinking fund plus service loss, and (4) cost of sediment removal. The method used depends upon availability of data and the importance of benefits accruing from reduced rates of reservoir sedimentation in relation to the overall economic justification of a watershed program. The geologist should work closely with the economist to determine the type of economic analysis which should be made and type of field data needed for the specific type of analysis proposed.

The preferred method is the straight-line method of evaluation which requires determination of the average annual rate of sedimentation in acre-feet without the watershed program and an estimate of the

future rate with the program installed. This method of evaluation is used when there are a large number of reservoirs which must be evaluated and detailed studies of each are not possible. The average annual rate of sediment accumulation for each reservoir is estimated on the basis of projecting existing or measured sediment yield data to each reservoir with proper adjustment for watershed characteristics. This method will also be used for evaluating sediment damages to natural lakes.

The sinking fund and the sinking fund plus service loss methods of evaluation are used when available information clearly indicates that a reservoir will be replaced prior to any significant loss in services. In these methods, the useful life of the structure, with and without the program, must be determined in addition to the average annual rate of sediment accumulation.

Evaluation of reservoir sedimentation damages on the basis of cost of sediment removal requires estimating, in addition to the sediment yield, the average annual amount of sediment to be removed without the project and with the project. This method is used when information indicates that reservoir storage will be maintained by the removal of sediment.

Procedures for evaluation.--The first step in evaluating sedimentation damage to reservoirs in a watershed is the compilation of a list of the reservoirs including data on capacity, size of drainage area, use, date of construction, and cost of construction. Both existing and proposed reservoirs should be considered. By proposed reservoirs is meant not only proposed flood control, but any proposed reservoirs planned by Federal, State, or local interests. This information may be obtained from the Engineering and Watershed Planning Unit, Corps of Engineers, U.S. Bureau of Reclamation, State Conservation Commissions, State water organizations, City officials, County engineers, and by personal inspection.

Following this it will be necessary to develop rates of capacity loss for each reservoir. These rates should be based upon sediment yields determined from existing reservoir sedimentation surveys and suspended sediment studies available in the watershed or within the same physiographic area.

Evaluating Gully Erosion Damages

Gully erosion is evaluated in terms of land damage, land depreciation, and sediment produced. This requires prediction of the average annual future rate of gully advancement and the corresponding width and depth of the gully. Since rate of gully advancement, widening and deepening, is not a straight-line relationship with time, the projection of the past historic rate may result in considerable errors of prediction. Acceptable procedures for adjusting the historic rate to probable future rate in respect to variable watershed and precipitation characteristics are set forth in "Procedure for Determining Rates of Land Damage, Land Depreciation and Volume of Sediment Produced by Gully Erosion," [3].

Land loss is determined by the actual area voided by the gully. The basis for determining area depreciated by the gully requires a projection of the probable gully system during the evaluation period and the influence of this system on land values. The evaluation of damages and benefits is a joint responsibility of the geologist and economist so that close coordination in developing information is required.

Evaluating Other Types of Sedimentation Damages

Water Supplies

The important aspects of surface water use should be determined for a watershed survey when project measures will have an effect on these supplies. This includes municipal, industrial, and other uses; the quantities of water used; and the costs of filtration. This information is usually available from the State Board of Health, together with data on population served and millions of gallons used annually. Additional information can be obtained by interviews with water departments concerned. Surface water supplies are often evaluated for entire basins by Federal, State and private agencies. These reports should be consulted.

In evaluating the effects of suspended sediment upon costs of filtration, only the costs of sediment removal should be included. These are alum treatment, increased frequency and cost of flushing filters, and removing sediment from other equipment and pipe lines.

Hydro-electric Power

Information concerning this type of damage must be obtained by interview with power companies concerned. The additional annual cost of maintaining turbines and other equipment in good condition may be obtained. This cost should include replacement parts, labor, power, and any other costs directly connected with repairing the damage caused by sediment.

Some power companies find it cheaper to prevent the damage than to repair it. They usually develop some method of dredging the sand or other material from the intake canal and preventing its reaching the turbines. In this case the annual cost of this dredging should be used as the damage. The Federal Power Commission reports on available and potential power developments for many areas. The reports should be consulted.

Transportation Facilites

The annual amount of sediment removed per mile from public highways should be obtained by counties or divisions from the State Highway Commission. County engineers may be able to furnish similar information for county and local roads, although township officials may have to be consulted in some cases. Railway division engineers can furnish the amount of sediment removal from railways. The total annual costs, or damages, may then be found by multiplying the cost per mile and the mileage of highways or railways affected in the watershed annually.

Drainage Ditches and Irrigation Canals

To determine this damage it is necessary to determine how much sediment has been removed by periodic cleanouts or how much has been spent for construction of desilting basins since the channels were constructed. Normal maintenance of channels, including such items as cutting brush, should not be included in this cost. The cleanout volume, times the unit cost divided by the number of years involved, yields the annual cost or damage. The benefits are determined on the basis of the expected rate of sedimentation with the program installed.

In the case of proposed floodways or channel improvements, the agency proposing the work usually estimates the amount and annual cost of sediment removal from the improved channel. This cost may be used as the damage.

In some cases, a drainage ditch or other channel may have been dug and have since partially filled with sediment. The ditch may have lost a part of its effectiveness but still may not have been impaired to such an extent as to make a cleanout necessary in the immediate future. In such a case, it is necessary to interview local residents, inspect the channel and make an estimate of the percentage loss of effectiveness which the channel has suffered since construction. This percentage multiplied by the original cost of the investment yields the total damage to date. This can be converted to an annual damage by dividing by the number of years involved.

Navigation Channels

The direct damage should include the cost of dredging and the losses incurred due to necessary light loading of ships, diversion of cargoes to other destinations, and shipment by rail instead of water because of sediment deposits in the channels. In evaluating dredging volumes, care should be taken to include only watershed sediment and to exclude the dredging of non-watershed sediment such as littoral sediment deposits which are brought into the harbor by shore currents, or municipal or industrial wastes dumped into the harbor or navigation channels.

If the navigation channels or pools involved are located downstream from the watershed being studied, it is then necessary to estimate what proportion of the total harmful sediment is coming from this watershed. The sediment yield can be derived from existing suspended sediment and reservoir sedimentation survey records if available, or may be computed from gross erosion and delivery ratio, if suitable field checks are available in the problem area. Only that portion of the annual cost of downstream dredging attributable to sediment contributed by the watershed under study may be used as a damage.

Increased Flood Stages

Since information on changes on the flood plain alone are of little value without information on channel changes, previously surveyed channel or valley cross sections, tied in to known elevations, are necessary for this type of study.

The original cross sections and the resurveys should be plotted on the same sheet. If comparison shows that there has been much channel filling or flood-plain aggradation, the party hydrologist will determine the increase in flooded area which may be attributed to sedimentation. The geologist will work closely with the hydrologist in this study. Where original cross sections are not available for resurvey, consult the EWP Unit to establish a recommended procedure.

Urban and Rural Fixed Improvements

Often sediments are deposited by floods in homes, factories, stores, sewers, wells, etc. The cost of removing this sediment is considered a damage. Such damage can be obtained by the economist in his appraisal of urban or fixed-improvement damages provided it is determined as a separate item. The benefits obtained in alleviating this damage will be sedimentation benefits.

Recreation

Where fish and wildlife are of primary importance to recreation, it may be necessary to evaluate sediment damages in this category.

Sediment damage to fish usually takes several forms. Sediment fills deep pools in streams which formerly served as refuges during prolonged droughts. The depth of the water must be greater than the thickness of ice that forms in the winter for fish to survive. Sediment disturbs fish spawning grounds. Reduction of light penetration due to high turbidity kills the small plants upon which the fish depend for food and oxygen. As a result, fish are usually much less plentiful in our present streams and lakes than they were formerly, and consist of less desirable species. Also, sportsmen are reluctant to fish in muddy streams and the loss of income due to this condition is evaluated as a damage resulting from sediment.

Sediment damage to wildlife is not so common as that to fish. Sediment may adversely affect the animals' habitat by destroying food sources, nesting sites and protective cover. If the damage is of sufficient magnitude to warrant a study, the damage to wildlife should be evaluated.

Recreation facilities also are damaged by sediment. On some lakes the water stays muddy so much of the time that swimming must be prohibited or is undesirable. A damage of this type may be evaluated by determining the annual loss of income from sale of bathhouse facilities, refreshments, gasoline, and other items which would exist if recreation were permitted and attractive. In other cases, sandy beaches are frequently covered with deposits of mud. This necessitates periodical re-covering of the beaches with sand. The damage is simply the average annual cost of resanding.

It is advisable to consult with the biologist and recreation specialist in determining damages of this type.

Sediment Sources

General

A determination of the relative sources of sediment must be made: (1) to locate the origin of the damaging sediment; (2) to ascertain what portion of the damaging sediment is derived from any one source; (3) to ascertain what type of treatment to reduce sediment production and control waterborne sediment can be utilized; and (4) to determine what the relative effects of treating the various sources will have in reducing the sediment and related damages.

Sediment is derived primarily from two sources--sheet erosion and channel erosion. Sheet erosion occurs primarily in the uplands. Channel erosion occurs as a result of concentrated flow and applies to gully erosion, valley trenching, flood-plain scour, streambed and streambank erosion.

Several means of determining the amounts of erosion at source areas have been devised. Not only must the amount of material being eroded be determined, but also the character of the material and the proportion of the material from each source that becomes sediment. Detailed procedures for determining sources of sediment are covered in other technical guides [12].

Channel Erosion

Flood-plain scour.--The area damaged and the depth of flood-plain scour are determined by the flood plain damage survey. It is necessary to obtain the rate of scour. This rate may be determined by the range method as described previously. The volume of material eroded by scour is the average annual area damaged, multiplied by the weighted-average depth. To be compatible with other report figures, this volume is converted to weight. The volume weight relationship is usually considered to be 1,800 tons equal one acre-foot.

Streambank erosion.--The volume of streambank erosion may be computed by the same method outlined for flood-plain scour (also see below).

Valley trenching and gully erosion.--The volume of erosion products produced by valley trenching and gully erosion is computed by the method outlined in detail in other technical guides[3], when land damage and land depreciation are being evaluated in conjunction with the sediment source studies. If land loss and land depreciation are not being evaluated and the purpose of the information is solely to determine sediment sources, less accurate simplified methods may be used. These methods are described in detail elsewhere[12]. In this case there are four methods which may be used: (1) comparison of aerial photographs of different dates to determine annual rate of growth of trenches and gullies; (2) resurveying existing cross sections to determine differences in total channel areas; (3) assembly of historical data in order to determine average age of channels and average annual growth; and (4) field studies to estimate average

annual growth, either by lateral erosion or incision in terms of volume per unit length of channel. Annual channel erosion based on an estimated annual rate of growth is computed by the following equation:

$$S = (D)\ (L)\ (R)\ (N)\ (P)$$

Where S = Annual channel erosion, in cubic feet
D = Average depth of channel, in feet (bank erosion only)
L = Length of channel, in feet
R = Annual rate of erosion of banks or bed, in feet
N = Number of banks affected (bank erosion only)
P = Percent of bank or bed length eroding

Streambed erosion.--It is only in instances where the stream channel is degrading that streambed erosion is to be considered as a source of sediment. The procedures to be used are set forth earlier in this release and elsewhere [13]. Each study will be developed in counsultation with the Engineering and Watershed Planning Unit.

Sheet Erosion

Channel erosion is frequently obvious whereas sheet erosion is not readily apparent. Sheet erosion, because of the large area involved, may be the most important source of sediment in a watershed. Often sheet erosion provides little damaging sediment in terms of infertile deposition. However, it may be the primary source of sediment causing swamping, damage to reservoirs, drainage, irrigation and navigation channels, water supply, etc. It is a selective process and usually only the finer particles are transported out of a field and the coarser materials, if they move at all, are deposited near their source.

Means of estimating amounts of sheet erosion quantitatively are outlined in detail elsewhere [12]. In most parts of the country the so-called "soil-decline" equation developed from analysis of plot data from research stations is used for making long-term estimates. This equation, developed by G. W. Musgrave [14] and associates, is a means of quantitatively expressing soil loss in terms of the inherent erodibility of the soil, cover and management, length and degree of slope, and the maximum 30-minute 2-year frequency rainfall amount.

Conservation needs inventories are a source of data on which to base calculations of on-site sheet erosion. The distribution of soils, degree of slope and major cover conditions can be obtained directly from weighted acreage tabulations. The length of slope can be determined from measurements on the conservation survey maps. The erosion scale value for various types of cover can be determined from research records and field surveys. Rainfall data can be obtained from another Technical Release [12] as well as Technical Papers No. 25, 28, and 29 on Rainfall Intensity, Duration and Frequency, published by U.S. Department of Commerce, Weather Bureau.

The procedure set forth elsewhere in detail [12], can be used for past, present, or future conditions. Adaptations of this procedure

have been made for different parts of the country and may be obtained by consultation with EWP Unit personnel.

Other Sources of Sediment
Other sources of sediment are (a) roadside erosion which may be measured as a type of channel erosion; (b) debris from gravel-washing plants, industries and mines; (c) wind erosion; and (d) other special localized sources. Some of these sources such as debris from gravel-washing plants merit special studies, the procedures for which must be developed for the special circumstances encountered.

Sediment Yields

Definitions
The amount of sediment carried out of a watershed or to a measuring point in the watershed is called the sediment yield. It is a function of the amount of gross erosion in the watershed (sheet erosion plus channel erosion) and the efficiency of the stream system to transport eroded materials. Sediment yields, in order to be comparable, must be expressed on a weight, usually tons, rather than on a volumetric basis.

Methods of Estimating Sediment Yields

General.--Sediment yields from watersheds can be estimated by measuring sediment loads in streams; by direct application of existing sediment yield data from adjacent or nearby watersheds; and by estimating gross erosion and the sediment delivery ratio.

Sediment-load measuring stations.--This method is not considered feasible for work plan development purposes because of the long period of time and high costs involved to obtain a reliable record.

Direct application of data from nearby watersheds.--This method is applicable when adequate sediment yield data are available from adjacent or nearby watersheds, which, for all practical purposes, are similar in land use, topography, channelization, soils and rainfall conditions to the watershed in question. An example would include watersheds with single cover conditions such as rangeland or forested areas in a given problem area. If the topography and channelization of the measured areas are similar to that of the watershed in question, a fairly reliable estimate can be arrived at simply by adjusting for differences in watershed areas. As indicated previously, information on existing reservoir sedimentation surveys and inventories of sediment-load measuring stations are contained in publications of the Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources [5], [6], [7] and [8]. Additional published and unpublished sediment yield data may be available in the records of the Engineering and Watershed Planning Units.

Adjusting for drainage basin size can be done by simple proportion providing there is not a significant difference in the sizes of drainage

areas between the measured and unmeasured similar watersheds. If measured watersheds are more than twice or less than one-half as large as the unmeasured watershed, direct proportion is questionable because of differences in delivery ratio due to different sizes of drainage areas. Therefore, an adjustment needs to be made for differences in the sediment yield expected between such watersheds to arrive at a reasonable estimate. Existing studies indicate that sediment yield varies roughly with the 0.8 power of the watershed area and this relationship may be used for adjustment.

Where adequate existing data on sediment yields are not available, which is usually the case in small watershed work, such information can often be obtained by measuring the sediment accumulation in farm ponds or small reservoirs in or near the watershed. The selection and number of reservoirs for survey, and the accuracy of the surveys will be influenced by the proposed use of the results. The results may be used for either evaluating sediment damages, or to obtain basic data needed for developing sediment requirements in the design of structural works of improvement. In either event, adjustments need to be made for differences in watershed characteristics as outlined in the preceding paragraphs.

Gross erosion and sediment delivery ratios.--Estimating sediment yield on the basis of estimated gross erosion and sediment delivery ratio involves calculation of sheet erosion and field measurement of channel erosion. Detailed procedures for this are contained elsewhere [12]. When this method is used, field checks based on existing sediment yield measurements should be available to verify application of the method to the particular problem area.

The ratio of the sediment yield to the gross erosion, expressed in percent, is called the delivery ratio. Both the character and size of the watershed are important in respect to delivery ratio. The delivery ratio is higher for steep watersheds with extensive channelization than it is for gently sloping watersheds with few channels. It is also indirectly related to the size of the drainage area, becoming progressively higher as the size of the drainage area decreases.

The delivery ratio for channel-type erosion may be much higher than that for sheet erosion. Inasmuch as the materials eroded by channel erosion processes are generally close to the transport system, a much higher percentage of the material is fed directly into the system to become a part of the sediment load. Materials derived from sheet erosion processes, however, often move only short distances and lodge in areas remote from the transport system. They can remain in the same fields in which they orginated or can be deposited on more level slopes as colluvium. The portion of the total sediment load of a stream attributable to sheet erosion may be relatively small in comparison to the total amount of soil involved in the erosional process.

Sediment yields may be obtained by multiplying estimated gross erosion by the estimated sediment delivery ratio. Other means of determining sediment yields in terms of additional watershed parameters are under

study. When such prediction equations are proved acceptable, they may be used in those areas for which they were developed.

Relative Sources of Sediments

General

It is possible to arrive at an estimate of the relative importance of each source of sediment by analyzing sediment yields, sources of sediment, and the respective delivery ratios for the various sources [12]. The relative importance of each sediment source is used to determine the effect of the program on reduction of sediment yield and the proper allocation of benefits.

Procedure for Determination

The total amounts of the various types of erosion as previously computed may be converted to percentages. Then, in each sediment source area, the relative importance of each type of erosion is determined.

The percentages apply only to the erosion within the area. The relative importance of the various types of erosion to particular types of sediment damage will vary. Some types of sediment damage are caused largely by one type of sediment. The location of the damage area, whether in the headwaters or at the mouth of the river, also influences the relative importance of its sediment sources. Some types of sediment, after erosion, are redeposited at a short distance from their original source. All types of erosion may not occur in all parts of the area. It is, therefore, necessary to estimate the relative importance of the various sediment sources for each type of sediment damage. Use the measured relative erosion and delivery ratios in each area as a guide. Table 2-9 is an example of a tabulation of these estimates.

Table 2-9. Percent Sediment by Sources Related to Kinds of Damage

Kind of Damage	Source of Damaging Sediment				
	Sheet Erosion	Gully Erosion	Stream-bank Erosion	Flood Plain Scour	Road-side Erosion
Infertile deposition	50	5	30	10	5
Swamping	40	5	40	10	5
Farm ponds	95	2	--	--	3
Reservoir No. 1	65	5	10	5	15
Reservoir No. 2	75	10	--	--	15
Watershed Total	65	5	15	5	10

Evaluating Effects of the Watershed Program

General

Previous discussion has dealt primarily with locating sediment damage and sources of the sediment causing the damage. In recommending the types of measures to be applied and fixing their locations, both of the foregoing items must be known.

The geologist in cooperation with members of the work plan party and other SCS specialists must be able to recommend the types and locations of measures to reduce sediment and related damages and to evaluate the effects of these reductions to determine benefits. General procedures for evaluating benefits are developed in cooperation with other work plan party and EWP Unit technicians at the time of work outline preparation. The following general considerations will be helpful in determining the detailed procedures to be adopted.

Evaluation of Program Benefits

Sediment Damage Reduction

After the remedial program has been agreed upon, it is necessary to determine to what extent the sediment from each source will be reduced by proposed land treatment and structural measures. Sheet erosion from agricultural lands is usually the principal source of sediment in the humid parts of the country but is frequently of lesser importance in the arid and semi-arid regions. Where sheet erosion is an important source of the sediment creating damages, a detailed study of the expected reduction in sheet erosion by land treatment measures should be made. This requires evaluation of the effects of proposed conservation practices, which include such measures as contour cultivation, terracing, strip-cropping, diversion ditches and dikes, grass waterways, and "conservation" cropping systems which reduce sheet erosion. Other practices contributing to a reduction in sheet erosion may be fertilization, liming, reseeding of pastures, tree planting, and protection of woods. Headwater detention and storage structures will aid in trapping sediment from sheet erosion sources.

Shallow gullies may be controlled by vegetation, terraces, and diversion ditches. Usually a high degree of control can be expected by vegetative measures on shallow gullies.

Sediment from deep gullies is chiefly controlled by mechanical means such as grade stabilization structures, bank shaping, or other structural measures. Diversion dikes may also be used to lead the water away from the gully head.

Valley trenches usually require more elaborate stabilization structures for control than gullies because of their generally larger drainage areas. Vegetative control measures for the control of this type of erosion are of minor importance.

Streambank erosion is usually reduced by structural measures such as pipe and wire revetments, riprap, or loose rock jetties, and on very small streams by vegetative measures, such as willow plantings. In addition, the program may call for the removal from the channel of snags and debris which have been deflecting the current and causing bank erosion.

Where streambank erosion is primarily due to the forces of flowing water impinging on the banks, a benefit may be anticipated by control of the flow. The reduction in forces on the bank may be correlated with a reduction of forces transporting bed material.

The reduction in flood-plain scour should be evaluated for all tributary streams. Control of scour may be achieved by regulated outflow from retarding structures and other measures, including fills and dams across low points in the streambanks and seeding of areas subject to scour.

Highway and railway bank and ditch erosion can be controlled by stabilized waterways or terraced outlets. Terraces may carry much water away from roadside ditches. Desilting basins which utilize highways or railway embankments may catch sediment from highway or railway cuts.

Mine wastes may require tree planting and other vegetation for stabilization. Desilting basins or other structures may be necessary.

The percentage reduction of sediment contribution resulting from the program must be determined for each sediment source. In determining these values, the type of remedial program, the percentage of the eroding area that can be treated, and the delivery ratio of sediment to the primary damage area must be considered.

The recommended program will reduce the production of sediment; will be effective in controlling water-borne sediment; and will futher alleviate sedimentation damages by reducing the overbank flow that results in flood-plain deposition and scour. The sedimentation and related benefits allocated to each type of measure can be proportioned by the amount each measure contributes to the reduction in sediment production. Therefore, the amount of the reduction of each source of sediment must be estimated.

Land Damage Reduction

The evaluation of benefits resulting from reduction of land damage caused by gully erosion, valley trenching, streambank erosion, and flood-plain scour requires determination of the effect of the remedial program on each of these types of damage and the percentage of the eroding area that can be treated. In this way a reduction in each of these damages can be obtained.

Proposed Programs of Other Agencies

Proposed programs of other agencies, particularly reservoir construction, may have a considerable effect on existing sediment and land

damages. For example, bottomland damages such as infertile deposition, swamping, streambank erosion, and flood-plain scour may be eliminated by inundation under reservoir pools.

Infertile deposition, swamping and scour damage may also be reduced downstream from proposed reservoirs which act as sediment traps and, in the case of flood-control reservoirs, confine flood water to the channels downstream.

Existing reservoirs may benefit if new reservoirs are constructed upstream. Costs of water filtration and dredging of downstream navigation channels may be reduced. Other downstream sediment damage such as to highways, railways, and drainage ditches may be lessened if sediment is trapped in new reservoirs.

On the other hand, an additional damage potential will be created in the form of loss of storage capacity by sedimentation in the proposed reservoirs. All of these modifications of the existing damages in the light of programs proposed by other agencies can be converted to monetary terms. The average annual damage of each type in each sediment source area, with other authorized programs assumed to be in effect but without the program administered by the SCS, may then be summarized.

III. GROUND WATER

Purpose and Scope of Ground-Water Investigations

General

Ground-water investigations in work plan development deal with the occurrence, development, replenishment and management of ground water. They are made, when needed, to provide assistance to cooperators in Soil Conservation Districts and to provide information essential to the planning and design of works of improvement in authorized watersheds. General policy relative to such investigations is set forth in Engineering Memorandum 51 [15]. Technical information on ground water is contained in the SCS National Engineering Handbook, Section 18, Ground Water [16] and in the references listed therein. Additional information is available in various chapters of Section 8, Engineering Geology [4]; Section 15, Irrigation [17]; and Section 16, Drainage [18] of the SCS National Engineering Handbook and the practices listed under Wells and Spring Development in the Engineering Handbook for Work Unit Staffs.

Service activities in the fields of drainage and irrigation are phases of ground-water management for agricultural purposes. Necessary investigations in these fields normally are carried out in accordance with established procedures and by personnel trained in the application of standard investigational methods. Usually the geologist will participate in these investigations only when the complexity of conditions requires geologic interpretations.

During investigations for work plan development, consideration must be given to ground-water conditions in the watershed and their relation to damages, benefits, and the proposed works of improvement. Ground-water investigations should be carried out to the extent necessary to determine the damage and benefit values used for evaluation purposes. Investigations also should be made to the extent necessary to ascertain that ground-water conditions after installation will not render any proposed work of improvement economically infeasible because of induced damages.

Evaluating Damages

Problems

Such problems as wet basements, impeded sewage disposal, unstable foundations, and impaired crop production may result from a high water table. This may be a natural condition or it may be the result of sedimentation or of a cultural development. Further, the condition may be perennial, seasonal, or it may only develop in association with special events such as a certain type of flood-producing storm.

Ground water usually is an important factor in the development of mass movement features such as slumps and earth flows and may be

an important factor in gully or channel erosion.

Removal of ground water through wells or by valley trenching may cause subsidence. This in turn may damage properties, works of improvement and other installations by cracking, disturbance in grade, differential settlement or other factors.

Adverse ground-water conditions at a structural site may so affect the design, construction, or functioning of the proposed structure as to render the site infeasible.

Other problems involve use of the ground-water reservoir as a source of water. This may include locating horizons from which ground water can be obtained and determining the yield and quality of such water and the possibility of recharging the reservoir.

In addition, the proposed program may induce problems and damages through modification of the ground-water regimen.

Damages

General.--In work plan development, it is necessary to determine the average annual value of damage that will occur in the future without remedial measures. The damage is usually computed by projecting the present rate, or present rate of increase, over the evaluation period used. The present rate is calculated from what has occurred in the past. A reduction of damages is a benefit. A benefit can also be obtained in some cases by increasing the returns from the land above their present level through application of the proposed program. Such benefit can accrue whether the present condition is natural or the result of past damage although this would not be considered a damage reduction in the sense used in the work plan.

On the other hand, the proposed program can cause or increase damages and these should be evaluated and computed as an induced damage in evaluating the program. Adverse effects of ground water usually do not require new or added procedures for evaluating damages or benefits. However, additional studies may be needed to establish the part ground water plays and to show where possibilities for remedial action may lie.

Changing water tables.--Where damage results from a rising or falling water table, a field inspection and interviews with property owners and operators and those responsible for the operation and maintenance of the facility, plus review of records, newspaper accounts, and similar data usually will furnish a basis for determining the extent, degree, and frequency of the damage. It will be necessary, however, to relate the problem to the ground-water regimen. It should be determined whether it is a natural geologic condition, an induced condition that has been caused by a cultural development or by some process such as channel aggradation or a problem related to some special event such as flood runoff of certain characteristics. In many instances of damage from ground

water, the cause can be attributed to such things as excessive runoff, accelerated sedimentation, channel filling, or some cultural development. Usually, in these cases, the reduction of damage is not a ground-water problem. On the other hand, it is frequently possible to obtain benefits by reducing the damage that has occurred in the past. This may require ground-water management. Similarly, natural conditions can often be improved through water table control.

Mass movement.--Mass movement features such as slumps or earth flows commonly cause damage, especially to such cultural features as roads or railroads. Field inspection, interviews with persons responsible for repair and maintenance, review of records and study of aerial photographs will usually furnish a basis for determining damage. It will be necessary to determine the influence, if any, of ground-water conditions on the development of mass movements.

Channel erosion.--Where ground water is a factor in channel-erosion damage, its effect should be considered in determining the extent and rate of future damage. Detailed studies may be required to determine the effect of ground water on the rate of increase in this type of damage.

Program Formulation

Ground-water investigations are required in formulating the proposed program where: (1) modification of the ground-water regimen by the proposed program will result in accrual of benefit or change in future damage; (2) ground-water conditions at a site cause an appreciable increase in estimated cost or make the site questionable for the purpose for which the structure is planned, including consideration of ground-water levels and movement with the proposed structure in place; (3) use of the underground reservoir as a source of water or recharge of the underground reservoir are a necessary part of the water management program for the watershed; and (4) pollution control and water quality improvement are part of the program.

Types of measures.--Measures planned for ground-water management or the development of water supplies from, or the recharge of, the underground reservoir may include barriers to ground-water movement such as grout curtains or sheet piling; drainage measures such as tile lines, gravel drains, or open ditches; installation of wells and development of springs; and ditches, spreading basins, wells or development of natural openings for recharge purposes.

Benefits

Benefits may result from the prevention of future damage, from the improvement of existing conditions through control of the water table, through development of needed water supplies from a ground-water reservoir and from recharge of an underground reservoir.

When damage from ground water is caused by channel aggradation, channel degradation, flood flows or other conditions, the control

of the basic process will reduce this damage in the future.

Where prevention of damage depends on ground-water management or where benefit can accrue through control of the water table, measures designed to modify the direction and rate of movement of ground water or to raise or lower the water table must be employed. The extent to which the damage can be reduced or the present productivity increased must be determined so that the benefit can be evaluated.

Where measures are installed to develop needed supplies of water, the benefit should be evaluated in terms of the value of the water, the increase in resulting production, or the cost of alternate means of procuring the needed water.

Ground-water recharge.--Benefit from the recharge of ground-water reservoirs may accrue incidentally from a measure installed for other purposes or it may result from measures installed for this purpose. In either case the determination of the benefit requires a knowledge of the amount of water added to the underground reservoir and the unit value of that water. The unit value will depend on many factors such as type of use, percent recoverable, number of beneficiaries, severity of need and any change in recovery or processing costs as a result of recharge. Values from 5 to 100 dollars per acre foot have been used in specific cases.

Pollution must be avoided in recharging ground water. Sources of pollution include untreated sewage, waste products, detergents, sediment, toxic and noxious substances, fertilizers, saline water, and heat. Water to be used for recharge should be tested by qualified laboratories. Usually these are Federal, State or local health department laboratories.

Seepage from reservoirs and from channels in which flow is prolonged by the program are the most common sources of incidental recharge. Where it reaches the water table it may represent a computable benefit. In some instances, such seepage will not reach the water table or the intake area of a producing aquifer, but will return to the surface or reach a perched water table which contributes little or nothing to the producing horizon. On the other hand, where suitable conditions exist, measures can be designed to put appreciable amounts of surface water into the underground reservoir.

Ground-Water Investigations

Preliminary Investigations

In the work plan stage a preliminary ground-water investigation normally is adequate. This includes a review of available data, a study of aerial photos, and a careful surface examination of the area. Shallow hand auger holes or pits may be needed.

Data review.--Reports by the USGS and various State organizations concerned with ground water may furnish applicable data. Logs of

local wells may be useful along with data on water yield, producing aquifers, the depth and elevation of the water surface, and other pertinent information.

Aerial photo review.--The study and analysis of aerial photographs often will furnish information that is valuable in a ground-water study. Stratigraphic relations, mass movement features, seep or spring lines, the location of buried channels, areas of very shallow water table, geologic structure, and indications of lithologic boundaries are some of the features that may be pertinent. It is good practice to outline or otherwise indicate the location and extent of pertinent features, picked out under the stereoscope, on the photograph or on an overlay, for later checking in the field.

Field study.--Geologic data that may have special significance in the investigation of ground water includes the location and configuration of the water table, the direction and rate of movement of underground water, the relative permeability of the various rock and soil materials, stratigraphic information, the location and influence of structural features, and the grain size distribution of soil materials including an estimate of the percent of clay materials. The continuity or lenticularity of the different soil materials, their origin, and the location of exposures in valley walls, channel banks, or other natural outcrops may be of particular importance.

At proposed dam sites, pertinent data on materials up to the elevation of the anticipated water level for the design emergency spillway runoff should be included and determinations made of the possible ground-water conditions that will exist when water is at this level in the reservoir.

The quality of water should be ascertained to be suitable from tests made by agencies dealing in water quality control. If ground-water is to be used as a source for a potable supply, bacterial and chemical tests should be performed. State health laws must be complied with.

Preliminary ground-water report.--A report should be prepared whenever preliminary ground-water investigations are carried out. The report should state the problem, tell what was done in the investigation, describe the pertinent geologic conditions that exist, show the interpretation that was made, and discuss the type and extent of further investigations needed for design and construction. A map showing the location of exposures, springs, seeps, slumps, and similar features, as well as such information as water-table contours, should be completed for any holes, pits, or natural exposures that were examined. These should be attached to the report.

It is important that the date be recorded on which each observation of water level or ground-water condition was made. Also any available information on seasonal fluctuation in ground-water levels, response to local rainfall or runoff, probable source areas and whether the streams are perennial or seasonal should be included.

IV GEOLOGICAL INVESTIGATIONS FOR STRUCTURAL WORKS OF IMPROVEMENT

General

In addition to geologic investigations needed for formulation of land treatment and structural measures in work plan development, the geologist also conducts investigations to obtain geologic information needed for the design and construction of structural works of improvement. Although the geologist might be called upon to conduct geologic investigations for many different types of structures, the most common structural measures requiring such investigations in work plan development are channel improvement works, floodwater-retarding dams and multiple-purpose structures. Levees, pumping plants, tide gates and others are encountered only occasionally in work plan development. Engineering geology and engineering design are completed to the degree necessary to determine feasibility and costs in the planning stage, leaving as much of the details to the operations stage as possible. In some instances, however, it may be necessary to obtain more complete information and, occasionally, even to carry out a detailed site investigation.

Site Selection

The geologist should participate in the preliminary site selection. To be effective in this he must have a general knowledge of the geology of the watershed and some idea of what type of problems might be encountered. A review should be made of all existing data that might contain useful information on geologic conditions. A stereoscopic study of potential structure sites will provide much useful information for interpreting geologic conditions. Such topographic and geologic features as rock outcrops, faults, caverns, sinks, natural terraces, old channels, landslides, springs and seeps, stream patterns, and general valley shape may be discernible from aerial photographs. Some of these features may need to be verified by field checking.

Cultural features having an effect on the structures should be located and described. These include old dikes, mill races, railroad fills, ditches, and buried objects such as cables and pipelines.

Where mineral resources have been or may be withdrawn, the possibility of subsidence or leakage must be recognized. A photo study or field reconnaissance of the watershed will also provide an indication of cover limitations and stream patterns, critical erosion and sediment source areas, the location of swamps, lakes, gorges, and canyons, and flood plain features that may influence sediment delivery to potential dam sites; and the possibility of pollution from sewage, mine or industrial waste, dumps, refuse, or sediment.

With the above information it may be possible to quickly eliminate many sites and potential problems at other sites may be anticipated.

After a site has been selected the engineer and the geologist should collaborate in making adjustments in location, elevation, and orientation of the component parts of the structure to insure that engineering and known geologic features are properly related. Further adjustments may be necessary after more investigations on a specific site have been completed.

Preliminary Site Investigation

Details on planning, conducting and reporting on a preliminary site investigation are given in Chapter 6, Section 8, SCS National Engineering Handbook and need not be repeated here.

A preliminary site investigation should be made of all proposed major structures in the watershed during work plan preparation. This investigation should be made as soon as possible after selection of the site location. An early scheduling will allow time for more intensive study of critical geologic conditions if such become necessary during the period of work plan preparation.

Detailed Site Investigation

When conditions are such that a detailed site investigation is required in the planning stage, it must be conducted in accordance with instructions given in Section 8, SCS National Engineering Handbook and Engineering Memorandum SCS-33 [19].

Sediment Design Investigations

Details on conducting sediment design investigations are given in Engineering Memorandum 27 (Rev.) [20] and in Technical Release 12 [21].

In most instances it is advantageous to conduct detailed studies during work plan preparation to arrive at the sediment requirements for each structure included in the work plan. However, when a large number of structures with similar watershed characteristics are included in the work plan, sampling procedures may be used to estimate sediment requirements. The sampling procedure should be of sufficient breadth and intensity that the results will suffice for final design purposes. Any special watershed conditions that do not fit the sample must be investigated separately.

Information gathered for the preliminary site selection will also be valuable in deciding whether detailed or sampling procedures should be used and how the sites can be grouped for sampling. A form SCS 309, Reservoir Sedimentation Design Summary, must be completed for all sites in the work plan.

Geologic Investigations for Channel Improvements

Channel improvement includes the excavation of new channels and floodways, the enlargement or straightening of existing channels with or without dikes and levees, lined channels, and bar removal, brushing and snagging. Geologic investigations for channel improvement works are usually made in respect to problems of channel stability or problems of excavation and slope stability. Procedures for making geologic investigations of channels are in Technical

Release No. 25, Planning and Design of Open Channels [13].

Geologic Investigations of Other Engineering Works of Improvement
The geologist might, on occasion, be called upon to do foundation investigations for dikes and levees, drop structures, pumping plants, tide gates, syphons and other engineering works besides channels and dams. Generally, the procedures outlined in Section 8, Engineering Geology, SCS National Engineering Handbook [4]will be applicable to these structures. Any additional guidance needed is available from the EWP Unit engineering geologist on request.

Intensity of Investigations
Geologic investigations for structural works of improvement must be of sufficient intensity in the planning stage to: determine the physical feasibility of the proposed structure; determine sedimentation requirements; and to determine the extent of detailed subsurface investigation that may be required for design and construction. The geologist works closely with the planning engineer and other specialists in determining feasibility and points out any adverse geological features that may influence costs or operation of the structure.

Except for determining sediment requirements, the equivalent of a preliminary site investigation normally will meet the requirements of geologic investigation for work plan development. In some instances, however, it may be necessary to get more complete information and occasionally even to carry out a detailed site investigation at this time. Guidelines on the degree of intensity of geologic site investigations for structures are given in the succeeding paragraphs.

As stated previously, geologic investigations in the planning stage must be carried far enough to establish the physical and economic feasibility of the site with a reasonable degree of accuracy. A preliminary site examination usually will suffice where:

1. The geology of the watershed is simple and well known and physical data are available.
2. Geologic and construction experience in the area is extensive.
3. The benefit-cost ratio in the watershed is good and the cost per benefited acre is low, allowing cost estimates to be high enough to cover the correction of adverse conditions discovered in operations.
4. The site is not one upon which the completion of the program is dependent.
5. There is no doubt that adequate borrow material is available
6. The site is not for a multiple purpose dam.

However, a complete detailed site investigation may be necessary for all or part of a site where:

1. The structural geology and/or stratigraphy of the area are complex
2. Extensive rock or boulder excavation is anticipated.
3. Borrow material is scarce or of poor quality.
4. Foundation or borrow conditions may create special design problems.
5. Cut slopes may need stabilization.
6. The inclusion of the site is critical to the plan.
7. The site is for a large, high-hazard dam or channel.
8. There is little data or geologic and construction experience in the area.
9. The benefit-cost ratio is close or the cost per benefited acre is high.
10. The site is for a multiple-purpose structure. Except in the case of water supply for municipal or industrial purposes, the Service is directly responsible for both stability and water-holding ability of the structure.
11. Some States have laws which require a detailed investigation and report to the State.

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